

Nonthermal Synchrotron and Synchrotron Self-Compton Emission from GRBs: Predictions for *Swift* and *GLAST*

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Abstract. Results of a leptonic jet model for the prompt emission and early afterglows of GRBs are presented. The synchrotron component is modeled with the canonical Band spectrum and the synchrotron self-Compton component is calculated from the implied synchrotron-emitting electron spectrum in a relativistic plasma blob. In the comoving frame the magnetic field is assumed to be tangled and the electron and photon distributions are assumed to be isotropic. The Compton-scattered spectrum is calculated using the full Compton cross-section in the Thomson through Klein-Nishina using the Jones formula. Pair production photoabsorption, both from ambient radiation in the jet and from the extragalactic background light (EBL), is taken into account. Results are presented as a function of a small set of parameters: the Doppler factor, the observed variability timescale, the comoving magnetic field, the peak synchrotron flux, and the redshift of the burst. Model predictions will be tested by multiwavelength observations, including the *Swift* and *GLAST* satellites, which will provide unprecedented coverage of GRBs.

Keywords: radiation processes: nonthermal — Gamma rays: bursts — Gamma rays: theory

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INTRODUCTION

The nature of the prompt emission of gamma-ray bursts (GRBs) is still a mystery. The most successful theory to date in explaining GRBs and their afterglows is the fireball model. In this model, some mechanism, such as core-collapse supernovae in the case of long GRBs, and possibly compact object mergers in the case of short GRBs produces an expanding shell in a baryon-free environment. When the expanding shell collides with another shell or interstellar material, it produces shocks which accelerate electrons and causes the prompt emission. High energy nonthermal electrons can generate such luminous radiation through synchrotron emission and Compton scattering of synchrotron photons (synchrotron self-Compton or SSC). See Mészáros [1] for a recent review.

ONE ZONE SYNCHROTRON/SSC MODEL AND FITTING TECHNIQUE

In the one zone synchrotron/SSC model for GRBs, a portion of a spherical shell, directed along our line of sight with Doppler factor δ_D , is assumed to be filled with nonthermal, isotropically-distributed electrons and ions, and to entrain a homogeneous, randomly-

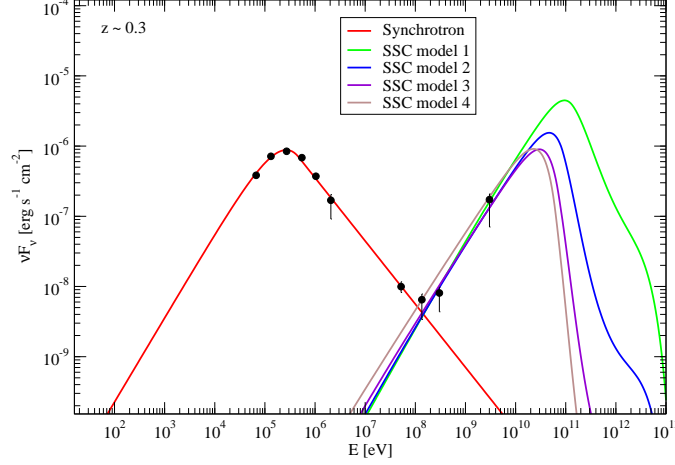


FIGURE 1. Synchrotron/SSC models for the GRB 940217 assuming $z \sim 0.3$.

oriented magnetic field, B . When simulating synchrotron/SSC emission from GRBs, the usual method is to inject an electron distribution and allow it to evolve, and then simultaneously fit the entire SED by synchrotron and SSC components [2]. This leads to a large number of parameters for the modeler to fit. We have developed a new approach, originally developed for TeV X-ray selected BL Lacertae objects [3]. In this technique, the low-energy component is assumed to be synchrotron emission; by fitting this with an empirical function, one can directly obtain the electron distribution using the δ -approximation for vF_v synchrotron flux,

$$f_{\varepsilon}^{\text{syn}} \cong \frac{\delta_D^4}{6\pi d_L^2} c \sigma_T U_B' \gamma_s'^3 N_e'(\gamma_s'), \quad (1)$$

[e.g., 4] where d_L is the luminosity distance, c is the speed of light, $U_B' = B^2/(8\pi)$ is the magnetic field energy density, ε is the observed dimensionless photon energy, $\gamma_s' = \sqrt{4 \times 10^{13} \varepsilon (1+z)/(\delta_D B)}$ is the electron Lorentz factor, and $N_e'(\gamma_s')$ is the electron distribution. In the case of GRBs, the synchrotron spectrum is fit with the empirical representation of Band et al. [5] which, in vF_v flux, is

$$f_{\varepsilon}^{\text{syn}} = \begin{cases} f_{\text{peak}} \left[\frac{\varepsilon}{\varepsilon_{\text{peak}}} \right]^a \exp \left[-a \left(\frac{\varepsilon}{\varepsilon_{\text{peak}}} - 1 \right) \right] & \left(\varepsilon \leq \frac{\varepsilon_{\text{peak}}(a-b)}{a} \right) \\ f_{\text{peak}} \left[\frac{(a-b)\varepsilon_{\text{peak}}}{a} \right]^{a-b} \frac{\varepsilon^b}{\varepsilon^a} e^b & \left(\varepsilon > \frac{\varepsilon_{\text{peak}}(a-b)}{a} \right) \end{cases} \quad (2)$$

where $f_{\text{peak}} = f_{\varepsilon}^{\text{syn}}(\varepsilon_{\text{peak}})$ and a and b are power-law indices. Once $N_e'(\gamma')$ is determined, the SSC flux can be calculated. We use the full Compton cross-section in the Thomson through Klein-Nishina regimes based on the formulae of Jones [6]. Assuming the redshift, z , of the burst is known, one can model the SSC emission as a function of a small set of parameters: δ_D , B , and $\Delta R'$, the (comoving) size scale of the emitting region. The value of $\Delta R'$ can be estimated from the observed variability time, t_{var} , based on light travel time arguments by $\Delta R' = \delta_D c t_{\text{var}}/(1+z)$, which effectively reduces the number of parameters in the fit to two. See Finke et al. [3] for more details on this technique.

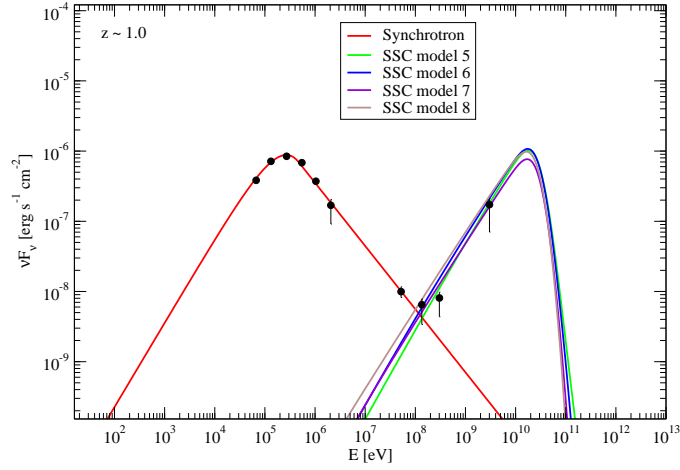


FIGURE 2. Synchrotron/SSC models for the GRB 940217 assuming $z \sim 1.0$.

The “jet” power, the power available in the expanding shell that can create observed radiation, is a combination of the power in the nonthermal particles and in the magnetic field of the emitting region [7]. It gives the upper limit on the observed isotropic luminosity, and is calculated by $L_j = 2\pi\Delta R'\beta\Gamma^2c(U'_B + U'_p)$, where U'_p is the particle energy density. The jet power can also allow one to constrain the magnetic field, by finding the magnetic field strength which minimizes this power [8].

EXAMPLE: FITS TO GRB 940217

As an example of this technique, we fit the GRB 940217 with this synchrotron/SSC model. The Compton Gamma-Ray Observatory *CGRO* observed this GRB, one of the longest and most energetic GRBs to be detected at GeV energies.[9]. We include absorption by internal jet radiation [10] and by the extragalactic background light [11]. The Band et al. [5] fit to the synchrotron spectrum gives the parameters $a = 1.2$, $b = -0.9$, $\epsilon_{peak} = 0.53$, and $f_{peak} = 8.8 \times 10^{-7} \text{ erg s}^{-1} \text{ cm}^{-2}$. The redshift to the GRB 940217 is unknown; however, it can be estimated to be $z \sim 0.3$ based on the correlation of Atteia [12]. This redshift value is used in models 1 – 4 (Fig. 1), while the value $z \sim 1.0$ is used in models 5 – 8 (Fig. 2). The parameters for these models can be seen in Table 1. In all models, the variability timescale was taken to be 1 sec, consistent with *CGRO* observations [9]. These fits were done in a “ χ -by-eye” fashion, although for better data, χ^2 minimization can be done [3].

At $z \sim 1.0$, the models are difficult to distinguish from each other, but at the lower redshift ($z \sim 0.3$), it is possible. although all of them give reasonable fits to the *CGRO* data. However, if the GRB had been observed by *GLAST* or a very high energy (VHE) γ -ray telescope, it would be possible to distinguish the models. Multiwavelength observations of future GRBs by *Swift*, *GLAST*, and VHE γ -ray telescopes such as MAGIC, VERITAS, and HESS will be key in discriminating between models. TeV γ -rays have not been conclusively detected from a GRB so far, and they would only be expected

TABLE 1. Model fit parameters

Model	B [G]	δ_D	L_j [erg s ⁻¹]
1	0.07	460	1.4×10^{55}
2	1.0	370	2.8×10^{53}
3	13	330	6.8×10^{51}
4	141	310	3.3×10^{50}
5	0.01	930	3.0×10^{56}
6	0.87	740	5.6×10^{54}
7	10	680	1.4×10^{53}
8	114	640	6.4×10^{51}

from nearby GRBs, as farther ones would have TeV radiation absorbed by the EBL.

At $z \sim 1.0$, the absorption is dominated by the EBL, and internal photoabsorption effects cannot be seen. However, the $z \sim 0.3$ models, while still dominated by EBL absorption, show curvature at TeV energies as a result of internal absorption. Such curvature in low-redshift GRBs is one of the key predictions of this model.

The GRB 940217 has an isotropic luminosity of $L_{iso} \approx 3.1 \times 10^{50}$ erg s⁻¹ if it is located at $z \sim 0.3$, and $L_{iso} \approx 5.0 \times 10^{51}$ erg s⁻¹ if it is at $z \sim 1.0$. Models which have powers in excess of these can be excluded.

We have summarized a new technique for modeling synchrotron/SSC broadband spectral energy distributions of GRBs and applied it to the GRB 940217. Although the data for this burst is sparse and the redshift is unknown, this nonetheless illustrates the method. When applied to future multiwavelength observations, this technique will be a good tool for testing the validity of the synchrotron/SSC model.

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